DECLARATION

I, the undersigned, of 2-12, Nakazaki 2-chome, Kita-ku, Osaka, Japan, hereby certify that I am well acquainted with the English and Japanese languages, that I am an experienced translator for patent matter, and that the attached document is a true English translation of

Japanese Patent Application No. **8-350612**

that was filed in Japanese.

I declare that all statements made herein of may own knowledge are true, that all statements on information and belief are believed to be true, and that these statements were made with the knowledge that willful statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Signature:

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(Translation)

[Name of the Document] SPECIFICATION

[Title of the Invention] Apparatus for fabricating semiconductor device, method for fabricating the same, optical evaluation apparatus and optical evaluation method

[Claims]

[Claim 1] A method for fabricating a semiconductor device, characterized by comprising the steps of:

forming a semiconductor wafer having a first semiconductor region, to be a part of a semiconductor element, and a second semiconductor region for optical monitoring;

irradiating measurement light onto the second semiconductor region from a direction vertical to a surface of the semiconductor wafer;

intermittently irradiating exciting light onto the second semiconductor region;

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the second semiconductor region depending upon whether or not the exciting light has been irradiated onto the second semiconductor region by a reflectivity of the measurement light from the second semiconductor region in the case where the exciting light has not

been irradiated onto the second semiconductor region, and thereby monitoring the variation amount of the reflectivity;

performing a processing treatment on the first and the second semiconductor regions simultaneously; and

controlling conditions for the processing treatment based on information about the variation in reflectivity of the measurement light.

[Claim 2] The method for fabricating a semiconductor device of Claim 1,

characterized in that, in the step of performing a processing treatment, an etching process is performed on the first semiconductor region and the second semiconductor region.

[Claim 3] The method for fabricating a semiconductor device of Claim 2,

characterized in that, in the step of performing a processing treatment, dry etching using plasma is performed.

[Claim 4] The method for fabricating a semiconductor device of Claim 2, further comprising the steps of:

depositing an interlevel insulating film on the first semiconductor region and the second semiconductor region on the semiconductor wafer; and

selectively removing the interlevel insulating film to form a first opening reaching the first semiconductor region and a second opening reaching the second semiconductor region,

characterized in that, in the step of performing a processing treatment on the first and the second semiconductor regions, light dry etching for removing a damaged layer formed in the vicinity of a surface, through which the first and the second semiconductor regions are exposed with each said opening formed, is performed,

and that, in the step of monitoring the variation amount of the reflectivity, a variation amount of an initial reflectivity of the second semiconductor region, before the interlevel insulating film has been formed, is detected beforehand and the variation amount of the reflectivity of the second semiconductor region, after each said opening has been formed, is monitored,

and that, in the step of controlling the conditions for a processing treatment,

the variation amount of the initial reflectivity and the variation amount of the reflectivity of the second semiconductor region, which varies as the etching proceeds, are compared with each other, thereby controlling the conditions for the etching processing treatment.

[Claim 5] The method for fabricating a semiconductor device of Claim 1,

characterized by further comprising a step of detecting a state of reflected light of the exciting light.

[Claim 6] The method for fabricating a semiconductor device of Claim 1, 2, 3, 4 or 5,

characterized in that a wavelength range of the measurement light is equal to or shorter than 600 nm.

[Claim 7] The method for fabricating a semiconductor device of Claim 1, 2, 3, 4, 5 or 6,

characterized in that, in the step of forming a semiconductor wafer, the second semiconductor region is provided in a region different from a region within the semiconductor wafer, in which a semiconductor chip, including the semiconductor element, is formed.

[Claim 8] The method for fabricating a semiconductor device of Claim 1, 2, 3, 4, 5 or 6,

characterized in that, in the step of forming a semiconductor wafer, the second semiconductor region is provided in a region within the semiconductor wafer, in which a semiconductor chip, including the semiconductor element, is formed.

[Claim 9] The method for fabricating a semiconductor device of Claim 1, 2, 3, 4, 5, 6, 7 or 8,

characterized in that, in the step of forming a semiconductor wafer, the first and the second semiconductor regions are made of n-type silicon single crystals.

[Claim 10] A method for fabricating a semiconductor device, characterized by comprising the steps of:

forming a semiconductor wafer having a first semiconductor region, to be a part of a semiconductor element, and a second semiconductor region for optical monitoring;

irradiating measurement light onto the second semiconductor region;

intermittently irradiating exciting light onto the second semiconductor region;

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the second semiconductor region depending upon whether or not the exciting light has been irradiated onto the second semiconductor region by a reflectivity of the measurement light from the second semiconductor region in the case where the exciting light has not been irradiated onto the second semiconductor region, and detecting a state of reflected light of the exciting light, thereby monitoring the variation amount of the reflectivity of measurement light and the state of the reflected light of the exciting light;

performing a processing treatment on the first and the second semiconductor regions simultaneously; and

controlling conditions for the processing treatment based on information about the variation in reflectivity of the measurement light and information about the reflected light of the exciting light.

[Claim 11] The method for fabricating a semiconductor device of Claim 10,

characterized in that, in the step of performing a processing treatment, an etching process is performed on the first semiconductor region and the second semiconductor region.

[Claim 12] An apparatus for fabricating a semiconductor device, characterized by comprising:

processing treatment means for performing a processing treatment on a semiconductor device;

first light incidence means for intermittently irradiating exciting light onto the semiconductor device;

second light incidence means for irradiating measurement light onto the semiconductor device from a direction vertical to a surface of the semiconductor device;

reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor device;

variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated from the first light incidence means; and

processing treatment control means for receiving an output of the variation calculation means and controlling conditions for the processing treatment based on the variation in reflectivity of the measurement light.

[Claim 13] The apparatus for fabricating a semiconductor device of Claim 12, further comprising

reflected exciting light detection means for detecting a state of the reflected light of the exciting light which has been irradiated onto the semiconductor device,

characterized in that the processing treatment control means receives the output of the variation calculation means and an output of the reflected exciting light detection means and controls conditions for the processing treatment based on the variation in reflectivity of the measurement light and the state of the reflected light of the exciting light.

[Claim 14] An apparatus for fabricating a semiconductor device, characterized by comprising:

processing treatment means for performing a processing treatment on a semiconductor device;

first light incidence means for intermittently irradiating exciting light onto the semiconductor device;

second light incidence means for irradiating measurement light onto the semiconductor device;

reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor device;

variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated from the first light incidence means;

reflected exciting light detection means for detecting a state of the reflected light of the exciting light which has been irradiated onto the semiconductor device; and

processing treatment control means for receiving an output of the variation calculation means and an output of the reflected exciting light detection means and controlling conditions for the processing treatment based on the variation in reflectivity of the measurement light and a state of the reflected light of the exciting light.

[Claim 15] The apparatus for fabricating a semiconductor device of Claim 12, 13 or 14,

characterized in that the processing treatment means performs plasma etching on the semiconductor device.

[Claim 16] An optical evaluation apparatus characterized by comprising:

a first light source for generating exciting light;

a second light source for generating measurement light;

a first light guiding member configured so as to intermittently irradiate the exciting light generated by the first light source onto a semiconductor region of a semiconductor substrate;

a second light guiding member configured so as to irradiate the measurement light generated by the second light source onto the semiconductor region from a direction vertical to the surface of the semiconductor substrate;

reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor region;

a third light guiding member configured so as to cause the measurement light reflected by the semiconductor region to be incident onto the reflectivity detection means; and

variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated.

[Claim 17] The optical evaluation apparatus of Claim 16, characterized by further comprising

reflected exciting light detection means for detecting a state of the exciting light, which has been reflected by the semiconductor region.

[Claim 18] The optical evaluation apparatus of Claim 16 or 17, further comprising

optical axis adjustment means configured so as to guide the exciting light and the measurement light onto a common optical axis and guide them to the semiconductor region,

characterized in that the second light guiding member is constituted by a mirror for irradiating the measurement light and the exciting light, which have been guided by the optical axis adjustment means onto the common optical axis, to the surface of the semiconductor region from a direction vertical thereto and for upwardly transmitting the measurement light and the exciting light reflected by the semiconductor region.

[Claim 19] The optical evaluation apparatus of Claim 16, 17 or 18, characterized by further comprising

spectroscope means for receiving at least the measurement light reflected by the semiconductor region, separating at least the measurement light, and then providing it to the re-flectivity detection means.

[Claim 20] The optical evaluation apparatus of Claim 16, 17 or 18, characterized by further comprising

a filter for receiving at least the measurement light reflected by the semiconductor region, transmitting only a component of the measurement light in a particular wavelength range, and then providing it to the reflectivity detection means.

[Claim 21] The optical evaluation apparatus of Claim 16, characterized in that

the first light source and the second light source are constituted by a single common light source for generating broad-spectrum light including a wavelength range of the exciting light and that of the measurement light,

and that the apparatus further comprises

a beam splitter for splitting the broad-spectrum light generated by the common light source into the exciting light and the measurement light, and

spectroscope means for receiving at least the measurement light reflected by the semiconductor region, separating the measurement light and then providing it to the reflectivity detection means,

and that the first and the second light guiding members are disposed at such positions as to receive the light from the splitter.

[Claim 22] An optical evaluation apparatus characterized by comprising:

a first light source for generating exciting light;

a second light source for generating measurement light;

a first light guiding member configured so as to intermittently irradiate the exciting light generated by the first light source onto a semiconductor region of a semiconductor substrate;

a second light guiding member configured so as to irradiate the measurement light generated by the second light source onto the semiconductor region;

reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor region;

variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated; and

reflected exciting light detection means for detecting a state of the exciting light, which has been reflected by the semiconductor region.

[Claim 23] An optical evaluation method characterized by comprising the steps of:

irradiating measurement light onto a semiconductor region of a semiconductor substrate from a direction vertical to a surface of the semiconductor substrate;

intermittently irradiating exciting light onto the semiconductor region; and

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the semiconductor region depending upon whether or not the exciting light has been irradiated onto the semiconductor region by a reflectivity of the measurement light from the semiconductor region in the case where the exciting light has not been irradiated onto the semiconductor region.

[Claim 24] The optical evaluation method of Claim 23, characterized by further comprising a step of

detecting a state of the exciting light reflected by the semiconductor region.

[Claim 25] The optical evaluation method of Claim 23 or 24, characterized by further comprising a step of:

separating light from a single light source into the exciting light and the measurement light prior to the step of irradiating the measurement light onto the semiconductor region and the step of intermittently irradiating the exciting light onto the semiconductor region.

[Claim 26] An optical evaluation method characterized by comprising the steps of:

irradiating measurement light onto a semiconductor region of a semiconductor substrate;

intermittently irradiating exciting light onto the semiconductor region;

calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the semiconductor region depending upon whether or not the exciting light has been irradiated onto the semiconductor region by a reflectivity of the measurement light from the semiconductor region in the case where the exciting light has not been irradiated onto the semiconductor region; and

detecting a state of the exciting light reflected by the semiconductor region.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a method for fabricating a semiconductor device and an apparatus for fabricating the same, and more particularly relates to improving the control of the characteristics of a semiconductor device during the fabrication process thereof.

[0002]

[Prior Art]

In recent years, semiconductor integrated circuits have achieved a remarkably high degree of integration. Thus, in a MOS type semiconductor device, efforts have also been made in order to develop a transistor device having an even smaller size and an even higher performance. Now that a transistor device of such a very small size has been provided, it is particularly necessary to realize a highly reliable MOS device. In order to improve the reliability of a MOS device, each portion constituting the MOS device is required to have high reliability.

[0003]

For example, the reliability of a contact portion, which is affected by a method for forming a contact window, is an important factor determining the reliability of such a MOS device. A damaged layer of a semiconductor substrate, which is produced by dry etching used for forming the contact window, is removed by wet etching subsequent to the dry etching. In order to appropriately determine the amount of removal, a monitor wafer or the like has conventionally been used for measuring the electric characteristic thereof, thereby sensing the depth and the like of the damaged layer produced under the dry-etching conditions. And various conditions, including duration, temperature and the like, are set for the

wet etching intended to remove the damaged layer. Thus, the conventional method for fabricating a semiconductor device performs a control so as to optimize the processing conditions during the fabricating process of the semiconductor device based on the electrical characteristics obtained by using the monitor wafer.

[0004]

In addition, a method using some microwave such as infrared rays is also known as a conventional method for evaluating a sample which has been damaged by plasma.

[0005]

[Problems to be Solved by the Invention]

By the way, as the size of a MOS device has been reduced, the planar size (lateral size) of a contact window has also been reduced, whereas the depth of the contact window has not been reduced. As a result, the aspect ratio (= depth/lateral size) is rather increased. And, in order to form such a contact window having a high aspect ratio, high-vacuum/high-density plasma has been used in a dry-etching process, for example. The high-vacuum/high-density plasma process has realized the formation of a deep contact window by using ions having high energy in satisfactorily aligned directions. However, the depth of the damaged layer, which is produced in semiconductor crystals on the bottom of a contact, and the degree of the damage have been increased by the impact of the

ions having high energy, as compared with the level of the defects which have been produced by a conventional dry etching process using relatively low-vacuum/low-density plasma.

[0006]

Thus, it is now difficult to surely remove the damaged layer or to remove the damaged layer with satisfactory controllability only by using the conventional method for fabricating a semiconductor device without applying any modification thereto.

[0007]

On the other hand, in the case of using microwave, since the light itself penetrates from the surface of a Si substrate into a depth of about 1 mm, it has been impossible to exactly evaluate the damage applied by actual plasma onto the Si substrate into a level of several tens nm. In other words, it has become substantially impossible to provide exact results for the evaluation of a damaged layer, the level of which will become increasingly closer to the surface as the size of an LSI is further reduced from now on, and for the evaluation of a region formed in an extremely small size.

[0008]

The above-described points are also true of various kinds of processing other than the etching process. Thus, a process and a control method, which can precisely and rapidly grasp the states of various factors affecting the character-

istics of a semiconductor device and which can realize desired characteristics for the semiconductor device with satisfactory reproducibility, are earnestly demanded.

[0009]

In view of these respects, the present invention has been devised and the objectives thereof are providing a structure for a semiconductor device which can realize satisfactory and uniform characteristics by surely grasping in-line the factors causing degradation in reliability of the semiconductor device and doing damage thereon during the fabrication process thereof, and providing a method for fabricating such a semiconductor device and an apparatus for fabricating the same.

[0010]

[Means for Solving the Problems]

In order to accomplish the above-described objectives, the present invention takes various means regarding a method for fabricating a semiconductor device which are recited in Claims 1 to 11, various means regarding an apparatus for fabricating a semiconductor device which are recited in Claims 12 to 15, various means regarding an optical evaluation apparatus which are recited in Claims 16 to 22 and various means regarding an optical evaluation method which are recited in Claims 23 to 26.

[0011]

As recited in Claim 1, the first method for fabricating a semiconductor device of the present invention includes the steps of: forming a semiconductor wafer having a first semiconductor region, to be a part of a semiconductor element, and a second semiconductor region for optical monitoring; irradiating measurement light onto the second semiconductor region from a direction vertical to a surface of the semiconductor wafer; intermittently irradiating exciting light onto the second semiconductor region; calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the second semiconductor region depending upon whether or not the exciting light has been irradiated onto the second semiconductor region by a reflectivity of the measurement light from the second semiconductor region in the case where the exciting light has not been irradiated onto the second semiconductor region and thereby monitoring the variation amount of the reflectivity; performing a processing treatment on the first and the second semiconductor regions simultaneously; and controlling conditions for the processing treatment based on information about the variation in reflectivity of the measurement light.

[0012]

In such a case, if the exciting light is irradiated onto the second semiconductor region, then the carriers are ex-

cited, and the electric field is varied in accordance with the variation in numbers of carriers. As a result, the reflectivity of the measurement light is varied. And, the period during which the carriers are in an excited state has certain longevity. The longevity is shortened if a large number of defects exist in the second semiconductor region, because the carriers are trapped by the defects. And, since the longevity of the carriers is shortened, the electric field formed by the carriers becomes small and the increase in reflectivity of the measurement light is attenuated. Thus, by monitoring the variation in reflectivity of the measurement light, various structural variations caused during the processing treatment of a semiconductor device can be monitored with certainty.

[0013]

As recited in Claim 2, in the step of performing a processing treatment of Claim 1, an etching process may be performed on the first semiconductor region and the second semiconductor region.

[0014]

This makes it possible to detect the depth of a damaged layer and the degree of the damage during the etching process and to perform a control to obtain appropriate etching conditions. Thus, as compared with a conventional fabrication method in which the electrical characteristics are detected

after an etching process has been completed and then fed back to the etching conditions, the characteristics of the semiconductor device can be controlled to obtain desired values with higher precision and smaller variation. Furthermore, since the measurement light is made to be incident onto the semiconductor wafer from a direction vertical thereto, optical measurements can be easily performed even if the second semiconductor region is a very small region, extra spaces for optical monitoring can be saved and the detection sensitivity is also improved. Thus, the time required for the evaluation of optical properties can be considerably reduced.

[0015]

As recited in Claim 3, in the step of performing a processing treatment of Claim 2, dry etching using plasma may be performed.

[0016]

This makes it possible to detect the degree of the damage, which is caused in the first semiconductor region owing to the impact of the ions during plasma processing, while monitoring the second semiconductor region. Thus, a semiconductor device having more satisfactory characteristics can be formed by a processing treatment using plasma, which is universally employed in the fabrication processes of a semiconductor device.

[0017]

As recited in Claim 4, the second method for fabricating a semiconductor device of the present invention includes, in addition to those of Claim 2, the steps of: depositing an interlevel insulating film on the first semiconductor region and the second semiconductor region of the semiconductor wafer; and selectively removing the interlevel insulating film to form a first opening reaching the first semiconductor region and a second opening reaching the second semiconductor region. In the step of performing a processing treatment on the first and the second semiconductor regions, light dry etching for removing a damaged layer formed in the vicinity of a surface, through which the first and the second semiconductor regions are exposed with each said opening formed, is performed. In the step of monitoring the variation amount of the reflectivity, a variation amount of an initial reflectivity of the second semiconductor region, before the interlevel insulating film has been formed, is detected beforehand and the variation amount of the reflectivity of the second semiconductor region, after each said opening has been formed, is monitored. In the step of controlling the conditions for a processing treatment, the variation amount of the initial reflectivity and the variation amount of the reflectivity of the second semiconductor region, which varies as the etching proceeds, are compared with each other, thereby controlling the conditions for the etching process.

[0018]

This makes it possible to suppress the generation of a new damage owing to excessive light dry etching, while surely removing the damaged layer which is formed in the first semiconductor region when the first opening, functioning as a contact hole of the semiconductor device, is formed.

[0019]

As recited in Claim 5, a step of detecting a state of reflected light of the exciting light may be further provided, in addition to those of Claim 1.

[0020]

This makes it possible to control the processing treatment by utilizing the information about the structural variation of the first and the second semiconductor regions which is obtained from the state of the reflected light of the exciting light.

[0021]

As recited in Claim 6, a wavelength range of the measurement light is preferably equal to or shorter than 600 nm in Claim 1, 2, 3, 4 or 5.

[0022]

As recited in Claim 7, in the step of forming a semiconductor wafer, the second semiconductor region may be provided in a region different from a region within the semiconductor wafer, in which a semiconductor chip, including the semicon-

ductor element, is formed in Claim 1, 2, 3, 4, 5 or 6. Alternatively, as recited in Claim 8, the second semiconductor region may also be provided in a region within the semiconductor wafer in which a semiconductor chip, including the semiconductor element, is formed.

[0023]

As recited in Claim 9, in the step of forming a semiconductor wafer, the first and the second semiconductor regions are preferably made of n-type silicon single crystals in Claim 1, 2, 3, 4, 5, 6, 7 or 8.

[0024]

As recited in Claim 10, the third method for fabricating a semiconductor device of the present invention includes the steps of: forming a semiconductor wafer having a first semiconductor region, to be a part of a semiconductor element, and a second semiconductor region for optical monitoring; irradiating measurement light onto the second semiconductor region; intermittently irradiating exciting light onto the second semiconductor region; calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the second semiconductor region depending upon whether or not the exciting light has been irradiated onto the second semiconductor region by a reflectivity of the measurement light from the second semiconductor region in the case where the excit-

ing light has not been irradiated onto the second semiconductor region, and detecting a state of reflected light of the exciting light, thereby monitoring the variation amount of the reflectivity of measurement light and the state of the reflected light of the exciting light; performing a processing treatment on the first and the second semiconductor regions simultaneously; and controlling conditions for the processing treatment based on information about the variation in reflectivity of the measurement light and information about the reflected light of the exciting light.

[0025]

This makes it possible to grasp, in more detail, the structural variations of the first and the second semiconductor regions, on which the processing treatment is performed, by utilizing the information about the variation in reflectivity of the measurement light and the information about the reflected light of the exciting light. As a result, a precise in-line process control can be performed.

[0026]

As recited in Claim 11, in the step of performing a processing treatment of Claim 10, an etching process may be performed on the first semiconductor region and the second semiconductor region.

[0027]

As recited in Claim 12, the first apparatus for fabricating a semiconductor device of the present invention includes: processing treatment means for performing a processing treatment on a semiconductor device; first light incidence means for intermittently irradiating exciting light onto the semiconductor device; second light incidence means for irradiating measurement light onto the semiconductor device from a direction vertical to a surface of the semiconductor device; reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor device; variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated from the first light incidence means; and processing treatment control means for receiving an output of the variation calculation means and controlling conditions for the processing treatment based on the variation in reflectivity.

[0028]

By using this apparatus for fabricating a semiconductor device, the method for fabricating a semiconductor device as recited in Claim 1 can be implemented easily. That is to say, by monitoring the variation amount of the reflectivity of the measurement light which has been incident onto the

surface of the semiconductor device from a direction vertical thereto, an apparatus for fabricating a semiconductor device, which can fabricate a semiconductor device having desired characteristics with satisfactory reproducibility, is obtained.

[0029]

As recited in Claim 13, reflected exciting light detection means for detecting a state of the reflected light of the exciting light which has been irradiated onto the semiconductor device may be provided, in addition to those of Claim 12. The processing treatment control means may receive the output of the variation calculation means and an output of the reflected exciting light detection means and may control conditions for the processing treatment based on the variation in reflectivity of the measurement light and the state of the reflected light of the exciting light.

[0030]

This makes it possible to perform a more precise process control by additionally utilizing the reflected light of the exciting light.

[0031]

As recited in Claim 14, the second apparatus for fabricating a semiconductor device of the present invention includes: processing treatment means for performing a processing treatment on a semiconductor device; first light

incidence means for intermittently irradiating exciting light onto the semiconductor device; second light incidence means for irradiating measurement light onto the semiconductor device; reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor device; variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated from the first light incidence means; reflected exciting light detection means for detecting a state of the reflected light of the exciting light which has been irradiated onto the semiconductor device; and processing treatment control means for receiving an output of the variation calculation means and an output of the reflected exciting light detection means and controlling conditions for the processing treatment based on the variation in reflectivity of the measurement light and a state of the reflected light of the exciting light.

[0032]

This makes it possible to perform a processing treatment control by utilizing the variation in reflectivity of the measurement light and the state of the reflected light of the exciting light. As a result, a semiconductor device having

desired characteristics can be fabricated with more satisfactory reproducibility.

[0033]

As recited in Claim 15, the processing treatment means of Claim 12, 13 or 14 may perform plasma etching on the semiconductor device.

[0034]

As recited in Claim 16, the first optical evaluation apparatus of the present invention includes: a first light source for generating exciting light; a second light source for generating measurement light; a first light guiding member configured so as to intermittently irradiate the exciting light generated by the first light source onto a semiconductor region of a semiconductor substrate; a second light guiding member configured so as to irradiate the measurement light generated by the second light source onto the semiconductor region from a direction vertical to the surface of the semiconductor substrate; reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor region; a third light guiding member configured so as to cause the measurement light reflected by the semiconductor region to be incident onto the reflectivity detection means; and variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement

light depending upon whether or not the exciting light has been irradiated.

[0035]

This makes it possible to evaluate the variation in reflectivity rapidly and precisely with respect to a very small semiconductor region because it is configured so as to irradiate the measurement light from a direction vertical to the surface of the semiconductor substrate. That is to say, an optical evaluation apparatus, which can perform optical evaluation during the fabrication process of a continuously miniaturized semiconductor device, can be obtained.

[0036]

As recited in Claim 17, reflected exciting light detection means for detecting a state of the exciting light which has been reflected by the semiconductor region may be provided in addition to those of Claim 16.

[0037]

This makes it possible to obtain an optical evaluation apparatus which can provide a wider variety of information.

[0038]

As recited in Claim 18, optical axis adjustment means configured so as to guide the exciting light and the measurement light onto a common optical axis and provide them to the semiconductor region may be further provided in Claim 16 or 17. The second light guiding member may be constituted by a

mirror for irradiating the measurement light and the exciting light, which have been guided by the optical axis adjustment means onto the common optical axis, to the surface of the semiconductor region from a direction vertical thereto and for upwardly transmitting the measurement light and the exciting light reflected by the semiconductor region.

[0039]

This makes it possible to perform an optical evaluation by utilizing the variation in reflectivity even when the semiconductor region is extremely narrow, because the exciting light is also irradiated from a direction vertical to the surface of the semiconductor region and because the reflected light thereof is guided upward. Thus, an apparatus suitable for detecting the processing state of a semiconductor substrate in real time can be obtained.

[0040]

As recited in Claim 19, spectroscope means for receiving at least the measurement light reflected by the semiconductor region, separating the measurement light, and then providing it to the reflectivity detection means may be further provided in Claim 16, 17 or 18.

[0041]

This makes it possible to detect only the variation in reflectivity of the measurement light having the most prefer-

able, particular wavelength. Thus, noiseless, high-sensitivity optical evaluation is realized.

[0042]

As recited in Claim 20, a filter for receiving at least the measurement light reflected by the semiconductor region, transmitting only a component of the measurement light in a particular wavelength range, and then providing it to the reflectivity detection means may be further provided in Claim 16, 17 or 18.

[0043]

This makes it possible to detect a variation in reflectivity of the light in a desired wavelength range even when the spectroscope means is not provided. Thus, the structure of the optical evaluation apparatus is simplified and noise-reduced, high-sensitivity optical evaluation is realized.

[0044]

As recited in Claim 21, the first light source and the second light source of Claim 16 may be constituted by a single common light source for generating broad-spectrum light including a wavelength range of the exciting light and that of the measurement light. A beam splitter for splitting the broad-spectrum light generated by the common light source into the exciting light and the measurement light, and spectroscope means for receiving at least the measurement light reflected by the semiconductor region, separating at least

the measurement light and then providing it to the reflectivity detection means may be further provided. The first and second light guiding members may be disposed at such positions as to receive the light from the splitter.

[0045]

Thus, the structure of an optical evaluation apparatus is extremely simplified because the light source may be single.

[0046]

As recited in Claim 22, the second optical evaluation apparatus of the present invention includes: a first light source for generating exciting light; a second light source for generating measurement light; a first light guiding member configured so as to intermittently irradiate the exciting light generated by the first light source onto a semiconductor region of a semiconductor substrate; a second light guiding member configured so as to irradiate the measurement light generated by the second light source onto the semiconductor region; reflectivity detection means for detecting a reflectivity of the measurement light irradiated onto the semiconductor region; variation calculation means for receiving an output of the reflectivity detection means and calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated; and reflected exciting light detection means

for detecting a state of the exciting light which has been reflected by the semiconductor region.

[0047]

This makes it possible to obtain an optical evaluation apparatus which can provide a lot of information about the structure of a semiconductor region by utilizing the variation in reflectivity of the measurement light and the state of the reflected light of the exciting light.

[0048]

As recited in Claim 23, the first optical evaluation method of the present invention includes the steps of: irradiating measurement light onto a semiconductor region of a semiconductor substrate from a direction vertical to a surface of the semiconductor substrate; intermittently irradiating exciting light onto the semiconductor region; and calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the semiconductor region depending upon whether or not the exciting light has been irradiated onto the semiconductor region by a reflectivity of the measurement light from the semiconductor region in the case where the exciting light has not been irradiated onto the semiconductor region.

[0049]

This makes it possible to get information about the structure of a semiconductor region rapidly and precisely.

[0050]

As recited in Claim 24, a step of detecting a state of the exciting light reflected by the semiconductor region may be provided in addition to those of Claim 19.

[0051]

This makes it possible to get a wider variety of information about the structure of a semiconductor region.

[0052]

As recited in Claim 25, a step of separating light from a single light source into the exciting light and the measurement light may be further provided in Claim 23 or 24 prior to the step of irradiating the measurement light onto the semiconductor region and the step of intermittently irradiating the exciting light onto the semiconductor region.

[0053]

This makes it possible to evaluate the optical properties of a semiconductor region by using an optical apparatus having only one light source.

[0054]

As recited in Claim 26, the second optical evaluation method of the present invention includes the steps of: irradiating measurement light onto a semiconductor region of a semiconductor substrate; intermittently irradiating exciting

light onto the semiconductor region; calculating, as a variation amount of a reflectivity, a value obtained by dividing a difference in reflectivity of the measurement light from the semiconductor region depending upon whether or not the exciting light has been irradiated onto the semiconductor region by a reflectivity of the measurement light from the semiconductor region in the case where the exciting light has not been irradiated onto the semiconductor region; and detecting a state of the exciting light reflected by the semiconductor region.

[0055]

This makes it possible to get a wider variety of optical information about the structure of a semiconductor region.

[0056]

[Embodiments of the Invention]

Hereinafter, embodiments of the present invention will be described.

[0057]

First, a method for fabricating a semiconductor device, the cross-sectional structure and the planar structure thereof according to this embodiment will be described with reference to Figures **1** to **3**. Figure **1** is a flow chart illustrating a method for fabricating a semiconductor wafer according to this embodiment. On the other hand, Figures **2(a)** through **2(c)** are cross-sectional views of a silicon wa-

fer illustrating the process steps for fabricating the semiconductor device according to this embodiment. Furthermore, Figure **3** is a top view schematically showing the structure of the silicon wafer according to the embodiment.

[0058]

As shown in Figure **3**, a chip region **Rtp** to be a semiconductor chip finally by being cut out of a wafer, and a monitor region **Rmn** for optical evaluation are provided on a p-type silicon wafer **103**.

[0059]

And, prior to the step illustrated in Figure **2(a)**, an n-type semiconductor region (a specific resistance value: about 0.02 Ωcm) **101** having an area of 13×13 mm^2, for example, has been formed in the monitor region **Rmn** on the silicon wafer **103**. On the other hand, various semiconductor elements have been formed in the chip region **Rtp**. In Figure **2(a)**, a MOS transistor including: a gate electrode **106** made of polysilicon; a gate oxide film **107** having a thickness of 6 nm, for example; an n-type source region **108**; and an n-type drain region **109**, is shown as an example thereof. And, an interlevel insulating film **104** is deposited over substantially the entire surface of the wafer. In this embodiment, the n-type semiconductor region **101** is doped an impurity having the same conductivity type and the same concentration as those of the n-type source region **108** and the n-type drain region **109**.

However, as will be described later, an impurity having a different conductivity type and a different concentration from those of the source/drain regions of the semiconductor element to be monitored may be doped into the semiconductor region in the monitor region **Rmn**.

[0060]

Next, in the step illustrated in Figure **2(b)**, a photoresist mask **105** for forming contact holes is formed on the interlevel insulating film **104**. Dry etching is performed in order to selectively remove the interlevel insulating film **104** by using the photoresist mask **105**. The dry etching is etching using plasma. The etching conditions are, for example, as follows. A mixed gas of Ar gas, CHF_3 gas, and CF_4 gas is used within a chamber (not shown). The flow rate of the Ar gas is 80 sccm, that of the CHF_3 gas is 45 sccm, and that of the CF_4 gas is 20 sccm. The overall gas pressure is set at 80 mTorr to cause radio frequency discharge with a power of 400 W. By this dry-etching process, not only the openings **110a** and **110b** which are contact holes respectively reaching the n-type source region **108** and the n-type drain region **109** of the MOS transistor, but also an opening for monitoring **110c** reaching the n-type semiconductor region **101** are formed. And, at a point in time when the completion of the formation of the respective openings **110a** to **110c** by the plasma luminescence method is detected, damaged layers **Rdm1**,

Rdm2 and **Rdm3** have respectively been formed in the n-type source region **108**, the n-type drain region **109**, and the n-type semiconductor region **101** on the silicon wafer **103**.

[0061]

Next, in the step illustrated in Figure **2(c)**, light etching (dry etching) is performed in order to remove the damaged layers **Rdm1** to **Rdm3** resulting from the dry etching. In this step, the present embodiment employs the conditions where the gas flow rates and pressure are not changed and the power is reduced to 200 W.

[0062]

Next, the principles of an optical evaluation method utilizing the variation of reflectivity will be described.

[0063]

In this embodiment, since the irradiation intensity of the measurement light (in each wavelength region) is assumed to be constant, detecting a reflection intensity of the measurement light is substituted for detecting a reflectivity. The measurement of the variation amount in reflection intensity of the measurement light is performed by continuously irradiating probe light **507**, which is Xe lamp light, from a direction vertical to the upper surface of the silicon wafer **103**, while intermittently irradiating the n-type semiconductor region **101** with exciting light **511**, which is Ar ion laser light, from an oblique direction, and then by detecting the

variation in intensity **R** of the reflected probe light **508** from the n-type semiconductor region **101**. That is to say, a value (Δ**R/R**) obtained by dividing a difference Δ**R** between the reflection intensity of the measurement light when the n-type semiconductor region **101** is irradiated with the exciting light **511** and the reflection intensity thereof when it is not irradiated with the exciting light **511** by the reflection intensity **R** when the n-type semiconductor region **101** is not irradiated with the exciting light **511** is defined as a variation amount in reflection intensity.

[0064]

Herein, it is considered that such a variation in reflection intensity of the measurement light results from the following action. In general, when semiconductor is irradiated with light, carriers are excited by the light to increase the number thereof. Thereafter, when the carriers return to the original energy level, they are extinct while emitting light. An electric field is varied in accordance with such a variation in numbers of carriers. Thus, the reflection intensity of the measurement light when exciting light is irradiated is different from the reflection intensity thereof when exciting is not irradiated. However, if a large number of defects exist in the semiconductor, then interface states at lower energy levels come to exist owing to the defects. And the defects having such interface states

function as a carrier-trapping layer. Thus, if the carriers are trapped by the defects so as not to be excited to sufficiently high energy levels even by the irradiation of light, and if the carriers, which have been excited to high energy levels, are trapped by the defects, then the intensity of the light, emitted when the excited carriers return to the low energy levels, is decreased. As a result, the electric field is also varied. Accordingly, the variation amount (Δ**R/R**) in reflection intensity of the measurement light becomes smaller as the depth of a damaged layer and the degree of damage become larger. Thus, information about the damaged layer can be obtained by monitoring the variation amount in reflection intensity of the measurement light.

[0065]

Figure **1** is a flow chart showing a procedure of the optical monitoring.

[0066]

First, in Step **ST1**, the initial variation amount of reflection intensity of the probe light (measurement light) in the n-type semiconductor region **101** before the interlevel insulating film **104** has been deposited, is measured. Next, plasma processing is performed in Step **ST102**, and the variation amount (Δ**R/R**) of the reflection intensity of the probe light is monitored in Step **ST103**. Further, in Step **ST104**, it is determined whether or not the removal of the damaged layer

has been completed, while comparing the increment amount rate (Δ**R/R**) of the reflection intensity of the probe light with the initial value. The processing in Steps **ST102** to **ST104** is repeatedly performed until the removal of the damaged layer is completed. When the removal of the damaged layer is completed, the plasma processing is ended in Step **ST105**.

[0067]

Figure **4** shows an optical monitoring system in an embodiment of the present invention. As shown in this figure, a Xe lamp **502** for generating probe light (wavelength: 376 nm, energy: 3.3 eV), which is measurement light to be irradiated onto the n-type semiconductor region **101**, is provided. The probe light **507** generated by the Xe lamp **502** is reflected by a mirror **506** and then provided onto the n-type semiconductor region **101** on the silicon wafer **103** disposed on a wafer stage **504**. And, the reflected probe light **508** reflected by the n-type semiconductor region **101** is passed through the mirror **506**, provided to a microscope system **505** and then the intensity thereof is detected by a system for observation and analysis **509**. In this embodiment, the irradiation of the probe light **507** onto the region to be observed and the take-out of the reflected probe light **508** can be performed from a direction vertical to the surface of a sample by using the microscope system **505** and the mirror **506** in combination. In addition, the diameter of the exciting light **511** can be re-

duced down to 50 $\mu m \phi$ by a lens **510**. It is noted that the data about the reflection intensity, which has been measured by the system for observation and analysis **509**, is transmitted to an etching control system (not shown) via a signal line.

[0068]

In addition, an Ar ion laser **503** for generating exciting light to be irradiated onto the n-type semiconductor region **101** and having an intensity of 5 W is also provided. The exciting light **511** from the Ar ion laser **503** is chopped by a chopper **510** at a frequency of 100 Hz and is intermittently irradiated onto the n-type semiconductor region **101**. And, as described above, a value (Δ**R/R**) obtained by dividing a difference Δ **R** in reflection intensities of the measurement light (probe light), which is caused depending upon whether or not the exciting light **511** has been irradiated, by the reflection intensity **R** when it is not irradiated with the exciting light **511** is detected by the system for observation and analysis **509** as the variation amount of the reflection intensity. The variation in variation amounts of the reflection intensity of the probe light is monitored by the above-described configuration. It is noted that a reflected exciting light observation system **513** for detecting the intensity of the reflected exciting light **512** from the semiconductor region **101** is also provided. The information about the intensity of the reflected exciting light **512** is transmitted to

the system for observation and analysis **509** via a signal line.

[0069]

It is noted that, in this embodiment and in the respective embodiment to be described later, the chopper **510** and a detector for detecting the intensity of reflected light are configured so as to operate in synchronism with each other.

[0070]

Hereinafter, the relationship between the variation amount in reflection intensity and the state of the damaged layer will be described. Figure **5** is a diagram showing the variation of the ratio of the variation amount in reflection intensity (**ΔR/R**) at a wavelength of 375 nm (energy: 3.3 eV) to the initial value thereof over the time. As shown in Figure **5**, the variation amount in reflection intensity (**ΔR/R**) immediately after the light etching is started (between 0 to 20 seconds) is larger than the value when the dry etching is completed in the main step to be closer to the initial value thereof. Thus, it can be understood that the damaged layers have been removed. However, as the light etching time increases (after 20 seconds has passed), the ratio of the variation amount in reflection intensity (**ΔR/R**) to the initial value thereof becomes gradually smaller than the value when the light etching is started (about 0.6 in the example shown in Figure **5**). Thus, it can be understood that the dam-

age done to Si crystals (substrate) is increased by excessive light etching.

[0071]

On the other hand, as shown in Figure **6**, the correlation between the light etching time and the resistance value (contact resistance) of a contact portion can be obtained by performing an experiment beforehand. As shown in Figure **6**, the contact resistance is high on the initial stage of the light etching because an organic polymer generated by the main etching has been deposited in the vicinity of the bottom face of the contact holes. It can be understood that it is gradually removed by the subsequent light etching. And, as can be seen from the comparison between Figures **6** and **5**, there is a correlation between the contact resistance and the variation amount in reflection intensity (**ΔR/R**) of the probe light. From the correlation, it can be understood that the variation amount in reflection intensity (**ΔR/R**) of the probe light must be a value corresponding to 60% or more of the initial value thereof in order to set the contact resistance at a nominal value (i.e., $50 \pm 5\,\Omega$ when the cross-sectional size of the contact window is $0.6\,\mu m$). Thus, by ending the light-etching step at a point in time when the variation amount in reflection intensity (**ΔR/R**) of the probe light reaches 60%, the generation of new damage, which might be caused by the subsequent light etching, can be suppressed,

while substantially removing the damaged layers resulting from the main etching. As a result, a semiconductor device having a satisfactory contact is realized.

[0072]

Figure **7** shows data for comparing the contact resistance of a MOS transistor formed by the light etching of this embodiment involving the optical monitoring for obtaining information about the damaged layers with the contact resistance of a MOS transistor formed by the conventional light etching not involving such optical monitoring. As shown in this figure, as compared with a conventional method, variations in contact resistance can be suppressed and a semiconductor device having higher quality and reliability can be fabricated by using the method for fabricating an apparatus for fabricating a semiconductor device of this embodiment.

[0073]

Figure **8** is data obtained by measuring the variation amount in reflection intensity of the probe light in the case where the intensity of the irradiated exciting light is varied for a sample on which the plasma processing has been performed and for a sample on which the plasma processing has not been performed. As can be understood from the data shown in this figure, the value of the variation in reflection intensity ($\Delta R/R$) of the probe light becomes smaller in the

sample on which the plasma processing has been performed, as compared with the sample on which the plasma processing has not been performed.

[0074]

Next, the advantages obtained by monitoring the damaged layers in accordance with the reflectivity spectroscopy as is done in this embodiment will be described. In general, the penetration depth of ions when plasma processing is performed is on the order of several tens nanometers. Since the penetration depth of microwave such as infrared rays into a semiconductor substrate is on the order of 1 mm, the information obtained from the reflectivity includes not only the information from the damaged layers but also a great deal of information from the regions other than the damaged layers. Thus, it is difficult to exactly take out information only about the damaged layers. Therefore, it is not a method appropriate for detecting such an extremely small region as that having etching damage. That is why, in the case of trying to get information about the structure of a semiconductor substrate in the vicinity of the surface thereof by using some microwave, the detection sensitivity is somehow improved in some cases by intentionally forming a silicon oxide film or the like having a thickness of about 100 nm on the semiconductor substrate. However, such a technique cannot be used for controlling a process in-line. On the other hand,

in the case of performing optical monitoring by using the light belonging to a range lower than that of visible light, the penetration depth thereof into the semiconductor substrate is at most on the order of several hundreds nanometers. Thus, the detection sensitivity with respect to the damaged layers having a depth of several tens nanometers becomes extremely high. Moreover, the information about the damaged layers can be directly got by irradiating light onto the surface of a semiconductor wafer, which is now being etched. Thus, by performing such optical monitoring using the light belonging to the range lower than that of visible light, it is possible to provide the information which is extremely useful for in-line evaluation and process control.

[0075]

Specifically, in the case of making the probe light incident onto the surface of a silicon wafer from a direction vertical thereto and detecting the reflection intensity thereof as is done in this embodiment, an extra space such as the monitoring region **Rmn** can be advantageously saved as compared with the case of making the probe light incident onto the surface of the substrate from a direction inclined thereto, because the evaluation of the Si damaged layers in a very small region can be performed easily. In addition, since the reflection intensity is also increased if it is made to be incident from a vertical direction, the evaluation

time is also shortened. For example, in the case where it is made to be incident onto the surface of the silicon wafer from the vertical direction, the evaluation time required for each wafer can be as short as 3 minutes. Thus, as compared with a case where it is made to be incident from a direction tilted by 45 degrees thereto, the evaluation time (15 minutes) can be considerably reduced. In the case of evaluating in-line the etch-damaged layers, the advantages to be attained by the shortening of the evaluation time are extremely effective.

[0076]

In this embodiment, a monitoring region **Rmn** is provided in the semiconductor wafer **103** separately from the chip region **Rtp**. However, the present invention is not limited to such an embodiment. Thus, the same effects as those attained by this embodiment can also be attained even when a pattern for optical evaluation is provided in the chip region **Rtp**. Furthermore, in the case where the probe light is irradiated onto the surface of a substrate from a direction vertical thereto, the contact window can be directly observed, even when the pattern for optical evaluation is not separately provided.

[0077]

In addition, since the reflected exciting light observation system **513** for observing the state of the reflected

exciting light **512** is provided, the information about the state of the reflected exciting light **512** may also be used for the process control.

[0078]

Furthermore, by controlling the variation in variation amounts of reflection intensity (**ΔR/R**) to be caused by a light-etching process within a predetermined time, the abnormality of a device can be detected rapidly and the trouble of the device can be prevented.

[0079]

In the above-described embodiment, the etching process is assumed to be dry etching using plasma. However, the present invention is not limited to such an embodiment. For example, the present invention is applicable to dry etching using sputtering gas or the like, not plasma, wet etching and the like.

[0080]

Moreover, the present invention is also applicable not only to etching for removing a damaged layer from a semiconductor region in which the damaged layer exists from the beginning, but also to etching performed when a semiconductor region substantially free from a damaged layer is etched. Furthermore, the optical evaluation method of the present invention may be utilized to get a wide variety of information about the structure of a semiconductor region, e.g., the de-

tection of a film thickness when a silicon oxide film is formed or removed, the detection of the degree of crystallinity recovery when a semiconductor substrate is subjected to an annealing process, and the like.

[0081]

Furthermore, in the above-described embodiment, the impurity concentration and the depth of the source/drain regions **108**, **109**, which are the first semiconductor regions in the chip region **Rtp**, are assumed to be equal to the impurity concentration and the depth of the n-type semiconductor region **101** in the monitoring region **Rmn** which is the second semiconductor region. However, the present invention is not limited to such an embodiment. The impurity concentrations and the conductivity types of the impurity of the first semiconductor region and the second semiconductor region may be different from each other. This is because, if only an experiment is performed beforehand, the optical properties (contact resistance in the above-described embodiment) in the second semiconductor region for obtaining an appropriate contact resistance for the first semiconductor region can be expected. For example, it is possible to improve the detection sensitivity of the variation amount in reflection intensity by setting the impurity concentration in the monitoring region **Rmn** at a particularly high value.

[0082]

(Second Embodiment)

In the following embodiment, an embodiment of an optical monitoring system will be described. It is noted that a semiconductor device may be processed in the same way as in the first embodiment described above and the modifiable embodiments noted above.

[0083]

Figure **9** is a perspective view showing an optical evaluation apparatus in this embodiment. In this figure, the same components as those shown in Figure **4** are identified by the same numerals. Specifically, in the same way as in the first embodiment, a wafer stage **504**, a Xe lamp **502**, a mirror **506**, an Ar ion laser **503**, a chopper **510** and a system for observation and analysis **509** are also provided. And, this embodiment is characterized by further including: a mirror **523** for guiding exciting light **511** and probe light **507** to the common axis; a spectroscope **521** for separating reflected light **518**, in which the exciting light and the probe light, reflected by an n-type semiconductor region of a silicon wafer **103**, are mixed; and a detector **522** for detecting the intensity of light at each wavelength of the light separated by the spectroscope **521**. An optical system **530** is constituted by the Xe lamp **502**, the mirrors **506** and **523**, the Ar ion laser **503**, the chopper **510** and the spectroscope **521**.

[0084]

In the optical evaluation apparatus of this embodiment, the probe light **507** generated by the Xe lamp **502** and the exciting light **511** generated by the Ar ion laser **503** are also guided onto the same axis by the mirror **523**, simultaneously reflected by the mirror **506** and then provided onto the n-type semiconductor region **101** on the silicon wafer **103** placed on the wafer stage **504**. Then, the reflected light **518** in which the reflected probe light and the reflected exciting light, reflected by the n-type semiconductor region, are mixed, is passed through the mirror **506** and then provided to the spectroscope **521**. After the intensity thereof has been detected by the detector **522**, a variation in the intensity thereof is analyzed by the system for observation and analysis **509**.

[0085]

Thus, by using the optical evaluation apparatus of this embodiment, a sample subjected to the plasma processing can be evaluated by a similar method to that described in the first embodiment. Moreover, since this embodiment is constituted so as to guide the probe light and the exciting light onto the common optical axis and then make them incident onto the n-type semiconductor region on the silicon wafer **103** as an observation point, alignment with the observation point can be performed very easily. In addition, the configuration of the apparatus is simplified. The evaluation of the Si damaged layer in an even smaller region can be performed more

easily by the configuration of this embodiment, as compared with the method shown in Figure **4** and described in the first embodiment. Moreover, since the exciting light is also incident from the vertical direction, the beam diameter can be converged down to about 30 μm, which allows for the evaluation of a sample at an even smaller observation point as compared with the case of making the exciting light incident from a direction tilted by 45 degrees thereto. Furthermore, the evaluation time can also be shortened to about 20% as compared with the first embodiment.

[0086]

Consequently, if there is a rather large semiconductor region in an LSI in a wafer, it is possible to measure the damages caused by the plasma processing and the like by utilizing it, even when a monitoring region is not provided separately in the wafer.

[0087]

(Third Embodiment)

Figure **10** is a perspective view showing an optical evaluation apparatus in the third embodiment. In this figure, the same components as those shown in Figure **9** are identified by the same numerals. Specifically, in the same way as in the second embodiment, a wafer stage **504**, an Xe lamp **502**, mirrors **506** and **523**, an Ar ion laser **503**, a chopper **510** and a system for observation and analysis **509** are also provided.

And, this embodiment is characterized by further including: a UV filter **525** (having a peak wavelength of 350 nm) for transmitting light in a predetermined wavelength range of the reflected light **518** in which the probe light and the exciting light, reflected by an n-type semiconductor region in a silicon wafer **103**, are mixed; and a detector **524** for detecting the intensity of the light transmitted through the UV filter **525**. An optical system **530** is constituted by the Xe lamp **502**, the mirrors **506** and **523**, the Ar ion laser **503**, the chopper **510** and the UV filter **525**.

[0088]

The optical evaluation apparatus of this embodiment can observe the variation amount in reflection intensity of the probe light in a predetermined wavelength range without separating it, unlike the methods of the foregoing embodiments. In accordance with this method, a time required for evaluation can be shortened to the order of several seconds.

[0089]

Figure **13** is a diagram showing the results obtained by measuring the variation amounts in reflection intensity (**Δ R/R**) of the probe light with the RF bias power varied, after light etching has been performed for 20 seconds by using the optical evaluation apparatus of this embodiment. In this case, the reflected probe light is not separated for spectral analysis, but the light, transmitted through the UV filter

525, is observed by the detector **524**. Thus, in view of the filtering characteristics, it can be considered that the results shown in this figure have been detected by integrating the intensity of the light in a wavelength range from 350 nm to 390 nm. As shown in Figure **13**, the higher the plasma intensity is set to be, the lower the variation amount (**ΔR/R**) in reflection intensity of the probe light becomes. Thus, it can be understood that the damage in the processed regions has been increased. That is to say, the method of this embodiment could also clearly detect the difference in variation amounts of the reflectivity of measurement light owing to the difference in processing degrees of plasma processing. As described above, since this embodiment does not require spectral analysis, the evaluation time could be shortened to the order of several seconds.

[0090]

(Fourth Embodiment)

Figure **11** is a perspective view showing an optical evaluation apparatus in the fourth embodiment. In this figure, the same components as those shown in Figure **9** are identified by the same numerals. Specifically, in the same way as in the second embodiment, a wafer stage **504**, a Xe lamp **502**, a chopper **510**, a spectroscope **521** and a detector **522** are also provided. And, this embodiment is characterized by further including: a beam splitter **526** for splitting the light

generated by the Xe lamp **502** into probe light **507** and exciting light **511**; a mirror **527** for reflecting the exciting light **511**; a mirror **528** for reflecting the probe light **507** and transmitting the reflected light **518** from a silicon wafer **103** therethrough; and a combinational mirror **529** for transmitting the probe light **507** therethrough and reflecting the exciting light **511** so that both of them are guided to the silicon wafer and for transmitting the reflected light therethrough in an optical system **530**. The optical system **530** is constituted by the Xe lamp **502**, the chopper **521**, the beam splitter **526**, the mirrors **527** and **528**, the combinational mirror **529** and the spectroscope **521**.

[0091]

Specifically, unlike the foregoing embodiments, the light from the Xe lamp **502** as a single light source is split in this embodiment into the probe light **507** and the exciting light **511** and then the reflectivity spectrometry is performed in the same way as in the respective embodiments described above. Thus, since the number of light sources may be one in this embodiment, the optical system **530** can be downsized as shown in Figure **11**. Moreover, since it is not necessary to use a laser, costs can be reduced and the maintenance efficiency can be improved.

[0092]

Figure **14** is a diagram showing the results obtained by measuring the variation amounts in reflection intensity (**Δ R/R**) of the probe light with the RF bias power varied, after light etching has been performed for 20 seconds by using the optical evaluation apparatus of this embodiment. As shown in Figure **14**, the higher the plasma intensity is set to be, the lower the variation amount (**ΔR/R**) in reflection intensity of the probe light becomes. Thus, it can be understood that the damage in the processed regions has been increased. That is to say, the method of this embodiment can also clearly detect the difference in variations of the reflectivity of measurement light owing to the difference in processing degrees of the plasma processing.

[0093]

Figure **15** is a diagram showing the results obtained by measuring the time-dependent variation in the ratios of the variation amounts (**ΔR/R**) in reflection intensity of the probe light to the initial value thereof at a wavelength of 376 nm (energy: 3.3 eV) by using the optical evaluation apparatus of this embodiment. As shown in this figure, as the light etching proceeds, the variation amount (**ΔR/R**) in reflection intensity of the probe light varies, in essence, in substantially the same manner as in Figure **5**. In this embodiment, however, the variation amounts (**Δ R/R**) in reflection intensity themselves are larger in value than

those shown in Figure **5**. This means that the sensitivity has been increased by additionally making the exciting light incident from above.

[0094]

(Embodiment commonly applicable to First to Fourth Embodiments)

Figure **12** is a cross-sectional view schematically showing the structure of a plasma processing apparatus commonly used in the foregoing embodiments. As shown in this figure, the plasma processing apparatus includes: a chamber **200**; an RF power supply **211** for supplying radio frequency power to generate plasma; a coupling capacitor **212**; a lower electrode **213** disposed on the bottom portion in the chamber **200**; an upper electrode **214** disposed on the ceiling portion in the chamber **200**; sight windows **218** and **219** provided through the side walls of the chamber **200**; and an observation window **220** provided in the vicinity of the center on the ceiling portion of the chamber **200**. It is noted that the illustration of a wafer stage is omitted from this figure. And, it is configured such that a plasma region **401** is produced between the upper electrode **214** and lower electrode **213** by the radio frequency power supplied from the RF power supply **211** so as to process an n-type semiconductor region **101** in a silicon wafer **103** placed on the lower electrode **213**.

[0095]

And, in the second to the fourth embodiments described above, the optical system **530** may be positioned collectively above the observation window **220** of the chamber **200** as shown in Figure **12**. In the first embodiment, only the optical system for probe light is positioned above the observation window **220**, while the optical system for exciting light is positioned beside the sight windows **218** and **219**.

[0096]

In the structure of such a plasma processing apparatus, at least the probe light can be incident onto the surface of the wafer from a direction vertical thereto. By observing the variation in reflectivity of the probe light, a process observation can be performed in real time. Feedback to processing conditions or the like can also be performed by using a signal **531** from the optical system.

[0097]

[Effects of the Invention]

According to Claims 1 to 9, when the first semiconductor region, a part of a semiconductor element, is subjected to a processing treatment, it is monitored how the reflectivity of the measurement light, which has been vertically incident onto the second semiconductor region provided on the same semiconductor wafer, is varied depending upon the presence/absence of the exciting light, and the conditions for the processing treatment on the first semiconductor region

are controlled in accordance with the variation in reflectivity. Thus, it is possible to provide a method for fabricating a semiconductor device, which can precisely and uniformly control the characteristics of the semiconductor device.

[0098]

According to Claims 10 and 11, when the first semiconductor region, a part of a semiconductor element, is subjected to a processing treatment, it is monitored how the reflectivity of the measurement light, which has been incident onto the second semiconductor region provided on the same semiconductor wafer, is varied depending upon the presence/absence of the exciting light, the state of the reflected light of the exciting light is also monitored, and the conditions for the processing treatment on the first semiconductor region are controlled in accordance with the variation in reflectivity and the state of the reflected light of the exciting light. Thus, it is possible to provide a method for fabricating a semiconductor device, which can precisely and uniformly control the characteristics of the semiconductor device.

[0099]

According to Claims 12 and 13, means for making measurement light incident onto a semiconductor device from a direction vertical thereto; means for making exciting light intermittently incident onto the semiconductor device; means

for measuring a reflectivity of the measurement light; means for calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated; and means for controlling conditions for the processing treatment on the semiconductor device based on the variation in reflectivity of the measurement light are provided for an apparatus for fabricating a semiconductor device. Thus, it is possible to provide an apparatus for fabricating a semiconductor device which can fabricate a semiconductor device having desired characteristics by utilizing the variation in reflectivity of the measurement light.

[0100]

According to Claims 14 and 15, means for making measurement light incident onto a semiconductor device; means for making exciting light intermittently incident onto the semiconductor device; means for measuring a reflectivity of the measurement light; means for calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated; means for detecting a state of reflected light of the exciting light; and means for controlling conditions for the processing treatment on the semiconductor device based on the variation in reflectivity of the measurement light and the state of the exciting light are provided for an apparatus for fabricating a semiconductor device. Thus, it is possible to provide an

apparatus for fabricating a semiconductor device which can fabricate a semiconductor device having desired characteristics by utilizing the variation in reflectivity of the measurement light and the state of the reflected light of the exciting light.

[0101]

According to Claims 16 to 21, means for making measurement light incident onto a semiconductor region from a direction vertical to a semiconductor substrate; means for making exciting light intermittently incident onto the semiconductor region; means for measuring a reflectivity of the measurement light; and means for calculating a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated are provided for an optical evaluation apparatus. Thus, it is possible to provide an optical evaluation apparatus which can rapidly and precisely detect the characteristics of a semiconductor region by utilizing the variation in reflectivity of the measurement light.

[0102]

According to Claim 22, means for making measurement light incident onto a semiconductor region of a semiconductor substrate; means for making exciting light intermittently incident onto the semiconductor region; means for measuring a reflectivity of the measurement light; means for calculating

a variation in reflectivity of the measurement light depending upon whether or not the exciting light has been irradiated; and means for detecting a state of reflected light of the exciting light are provided for an optical evaluation apparatus. Thus, it is possible to provide an optical evaluation apparatus which can detect a great deal of information about the structure of a semiconductor region by utilizing the variation in reflectivity of the measurement light and the state of the reflected light of the exciting light.

[0103]

According to Claims 23 to 25, a variation in reflectivity, in which the reflectivity of the measurement light, vertically incident onto a semiconductor region, is varied depending upon the presence/absence of the exciting light, is detected. Thus, it is possible to provide an optical evaluation method which can rapidly and precisely detect the information about the structure of the semiconductor region.

[0104]

According to Claim 26, the state where the reflectivity of the measurement light, vertically incident onto a semiconductor region, is varied depending upon the presence/absence of the exciting light and the state of the reflected light of the exciting light are detected. Thus, it is possible to provide an optical evaluation method which can detect a wide

variety of information about the structure of the semiconductor region.

[Brief Description of the Drawings]

[Figure 1]

A flow-chart diagram illustrating a method for fabricating a semiconductor device according to the first embodiment.

[Figure 2]

Cross-sectional views of a semiconductor wafer illustrating the process steps for fabricating a semiconductor device according to the first embodiment.

[Figure 3]

A top view of the semiconductor wafer according to the first embodiment.

[Figure 4]

A perspective view schematically showing an optical monitoring system of the semiconductor device according to the first embodiment.

[Figure 5]

A characteristic diagram showing the relationship between an etching time and the variation amount in reflection intensity of probe light in the first embodiment.

[Figure 6]

A characteristic diagram showing the relationship between an etching time and a contact resistance in the first embodiment.

[Figure 7]

A diagram showing different variations in contact resistance values of the semiconductor devices which have been formed by using a light etching method of the first embodiment and a conventional light etching method, respectively.

[Figure 8]

Data showing a difference in the characteristics between the intensity of the exciting light and the variation in reflectivity of the probe light for a sample on which the plasma processing of the first embodiment has been performed and for a sample on which the plasma processing has not been performed.

[Figure 9]

A perspective view schematically showing an optical monitoring system of the semiconductor device according to the second embodiment.

[Figure 10]

A perspective view schematically showing an optical monitoring system of the semiconductor device according to the third embodiment.

[Figure 11]

A perspective view schematically showing an optical monitoring system of the semiconductor device according to the fourth embodiment.

[Figure 12]

A cross-sectional view schematically showing a state in which the optical monitoring system of each embodiment is attached to a plasma processing apparatus.

[Figure 13]

A diagram in which the variation amounts in reflection intensity of the probe light are plotted with respect to variable RF power for the case where light etching is performed for 20 seconds by using the optical monitoring system of the third embodiment.

[Figure 14]

A diagram in which the variation amounts in reflection intensity of the probe light are plotted with respect to variable RF power for the case where light etching is performed for 20 seconds by using the optical monitoring system of the fourth embodiment.

[Figure 15]

A characteristic diagram showing the relationship between an etching time and the variation amount in reflection intensity of probe light in the fourth embodiment.

[Description of the Reference Numerals]

101 n-type semiconductor region

103 p-type silicon wafer

104 interlevel insulating film

105 photoresist mask

106 gate electrode

107 gate oxide film

108 n-type source region

109 n-type drain region

110a to **110c** opening

502 Xe lamp

503 Ar ion laser

504 wafer stage

505 microscope system

506 mirror

507 probe light

508 reflected probe light

509 system for observation and analysis

510 chopper

511 exciting light

512 reflected exciting light

513 reflected exciting light observation system

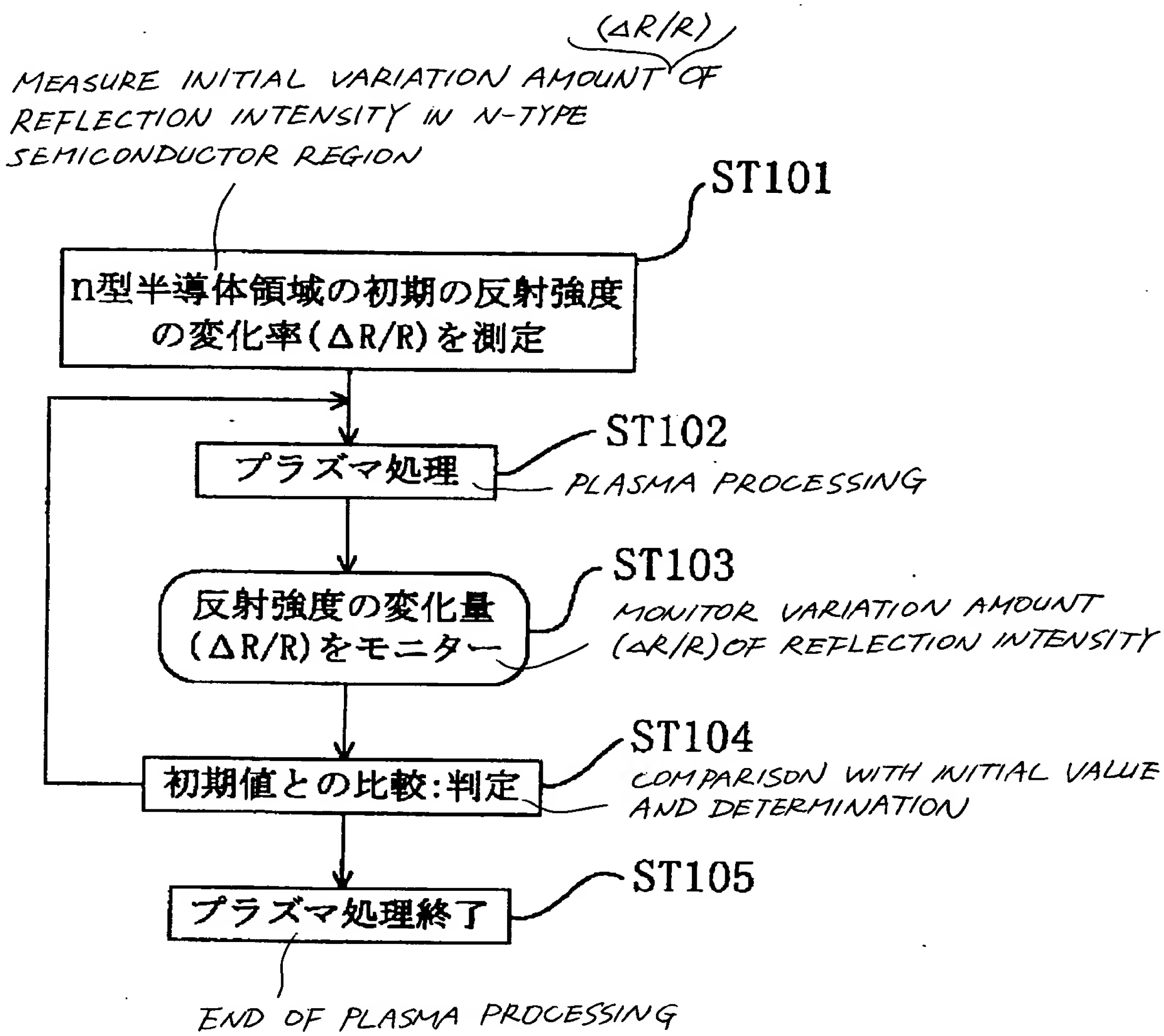
Rtp chip region

Rmn monitoring region

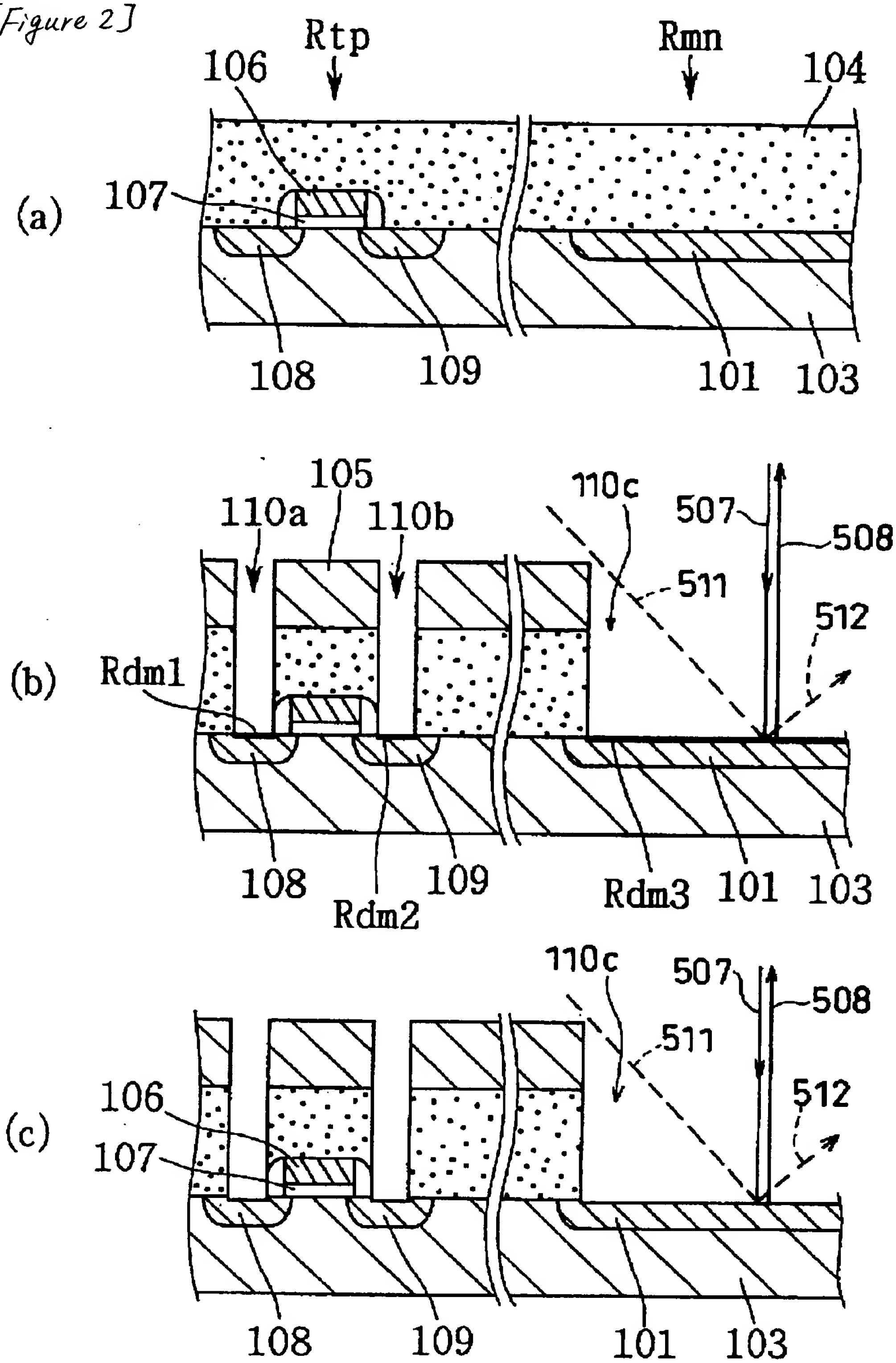
Rdm1 to **Rdm3** damaged layer

【書類名】　図面
[Name of the Document]　DRAWINGS

【図１】
[Figure 1]

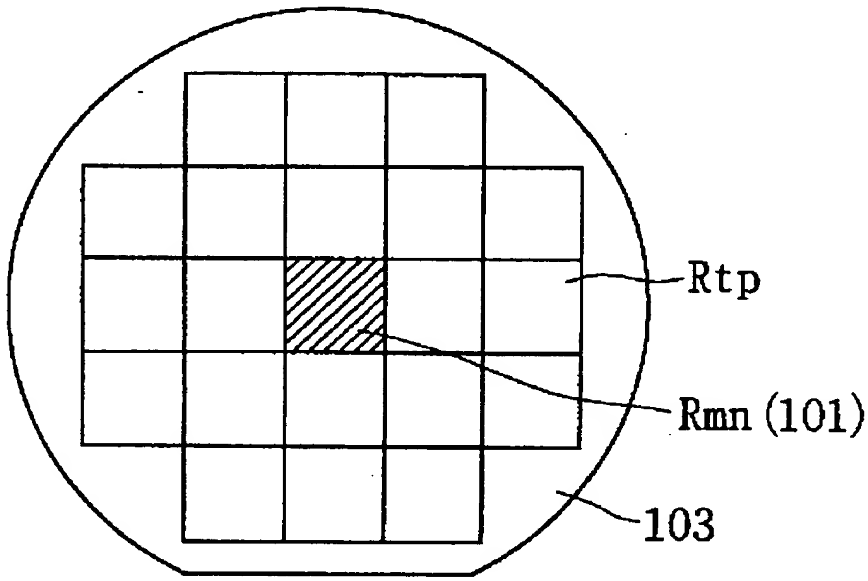


【図２】
[Figure 2]

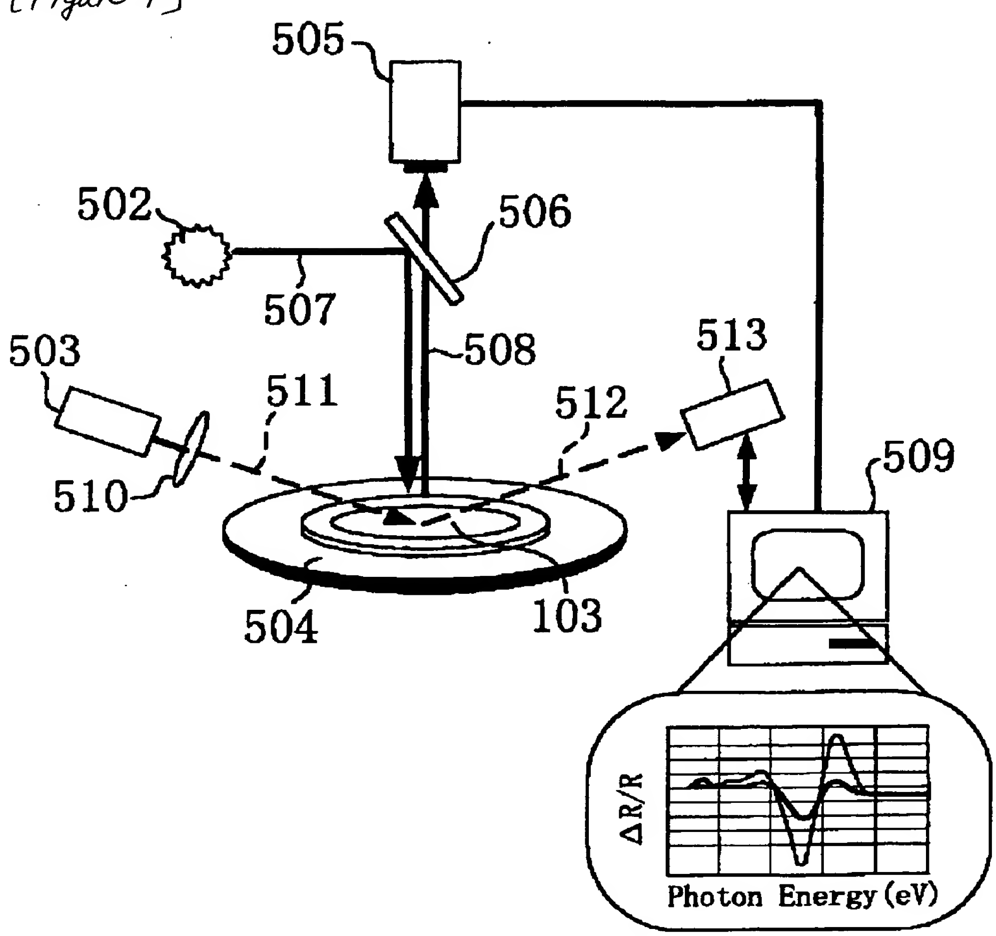


(a)
Rtp
Rmn
106
104
107
108
109
101
103
(b)
105
110a
110b
110c
507
508
511
512
Rdm1
108
Rdm2
109
Rdm3
101
103
(c)
110c
507
508
511
512
106
107
108
109
101
103

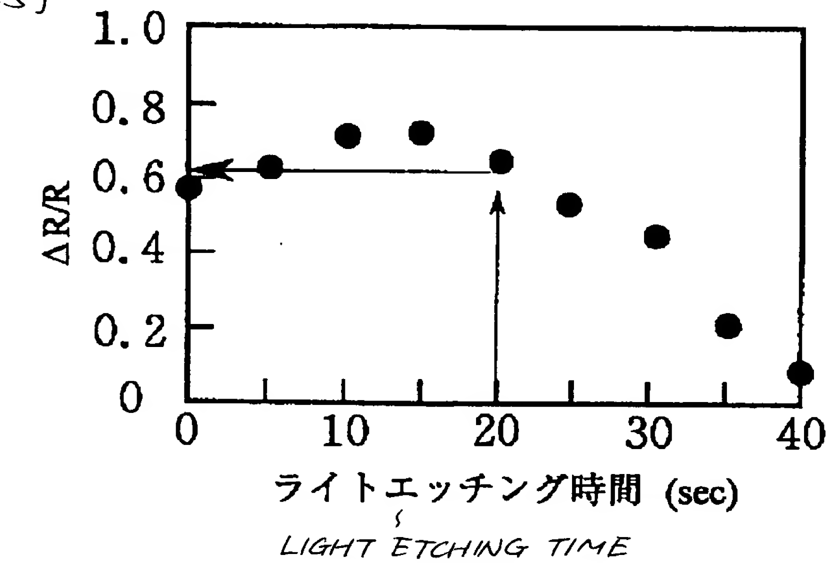
【図３】
[Figure 3]



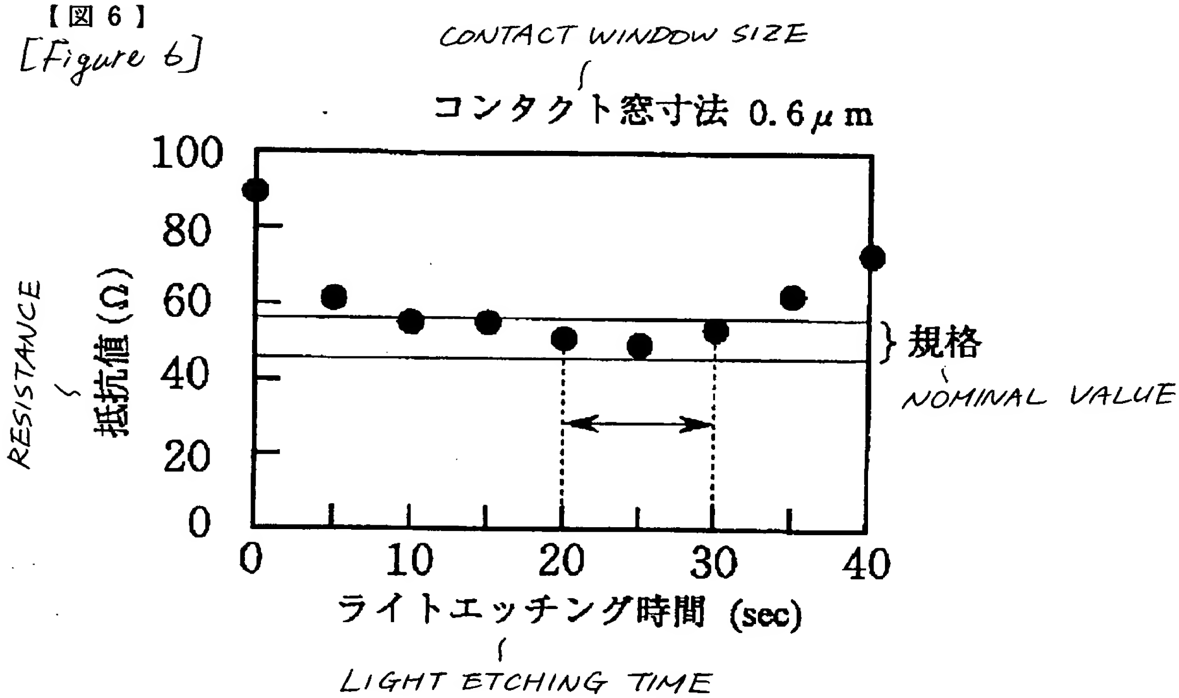
【図４】
[Figure 4]



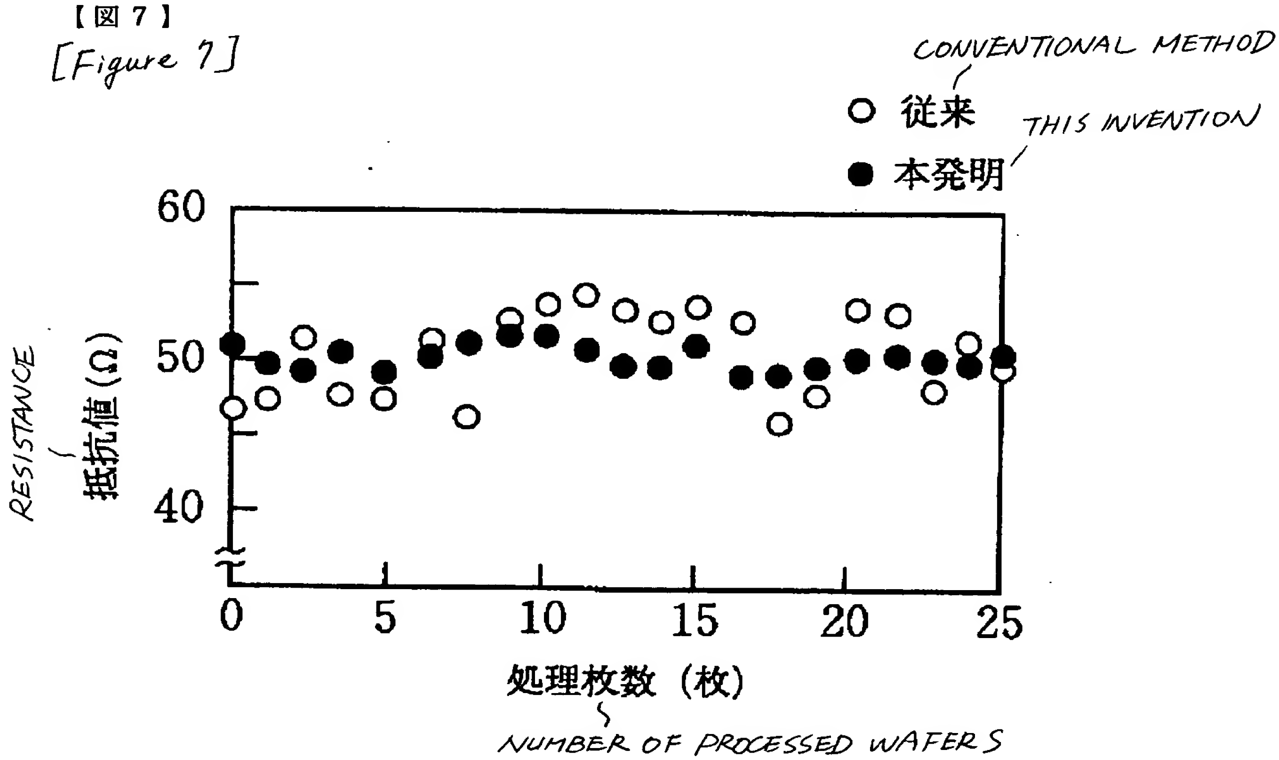
【図５】
[Figure 5]



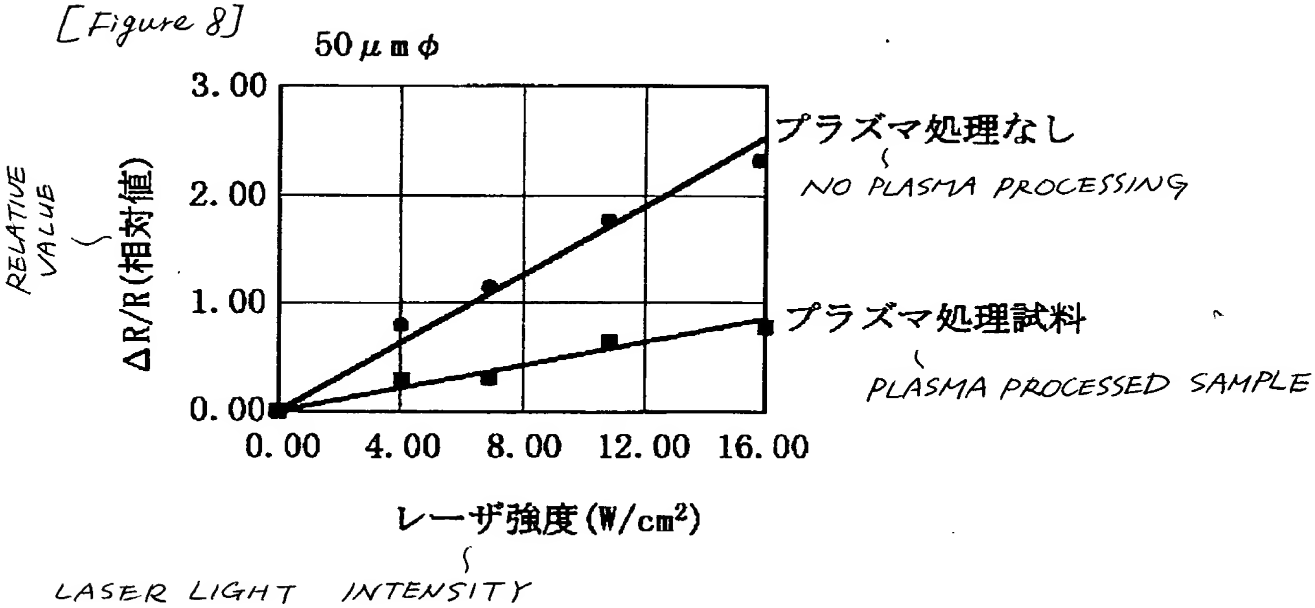
【図６】
[Figure 6]



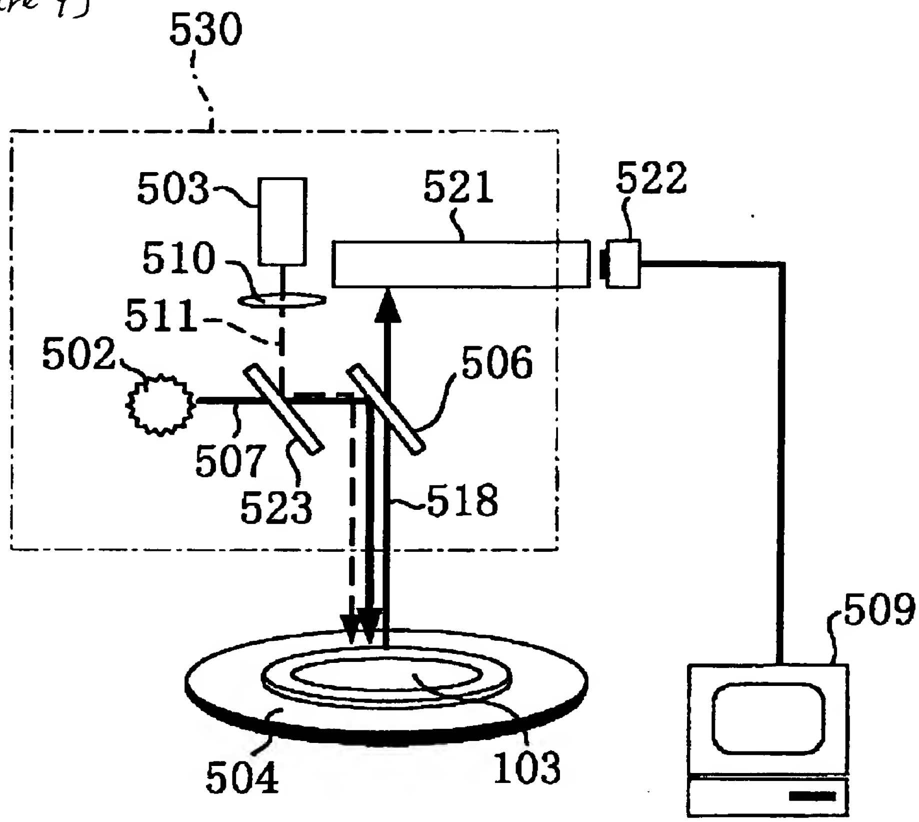
【図７】
[Figure 7]



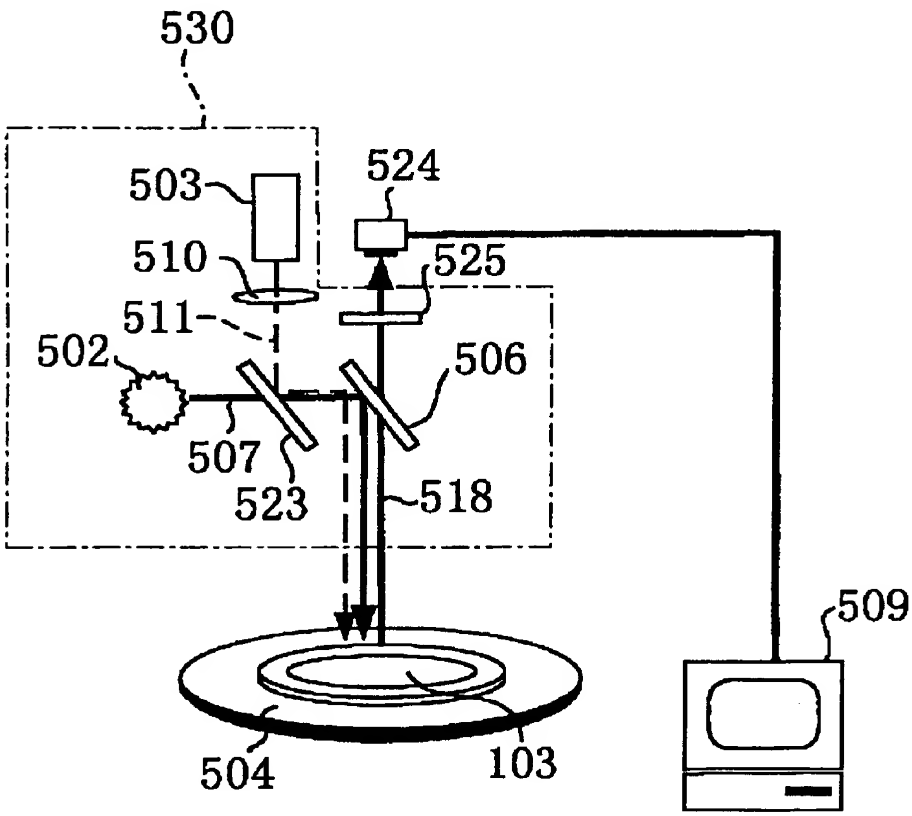
【図８】
[Figure 8]



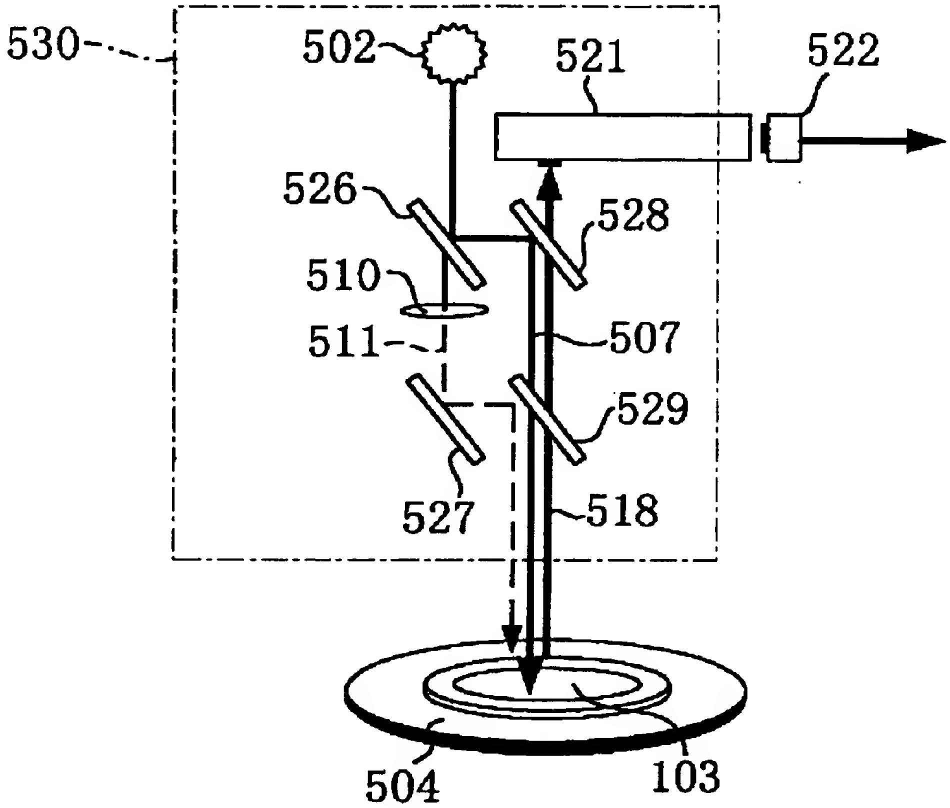
【図９】
[Figure 9]



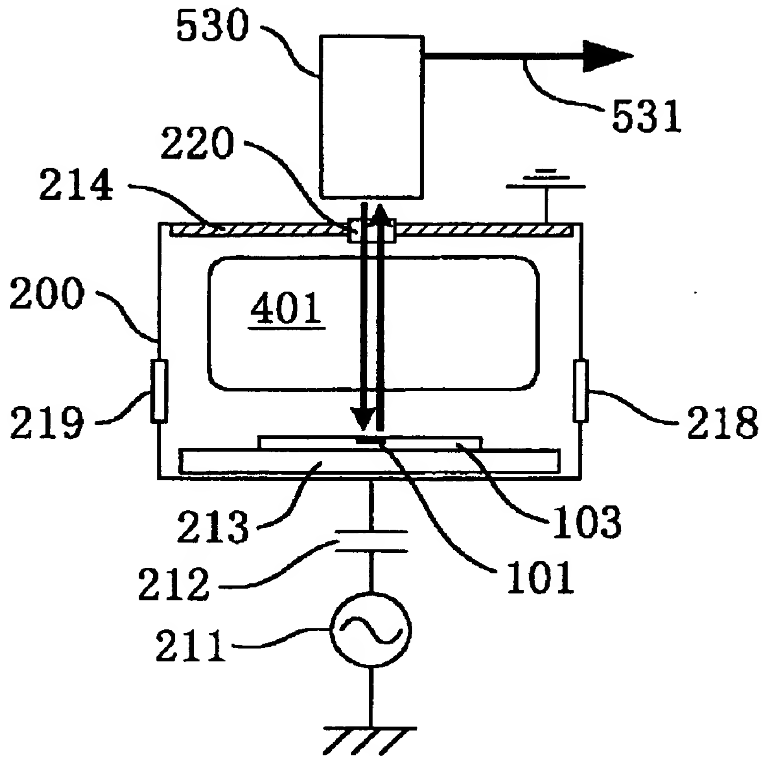
【図１０】
[Figure 10]



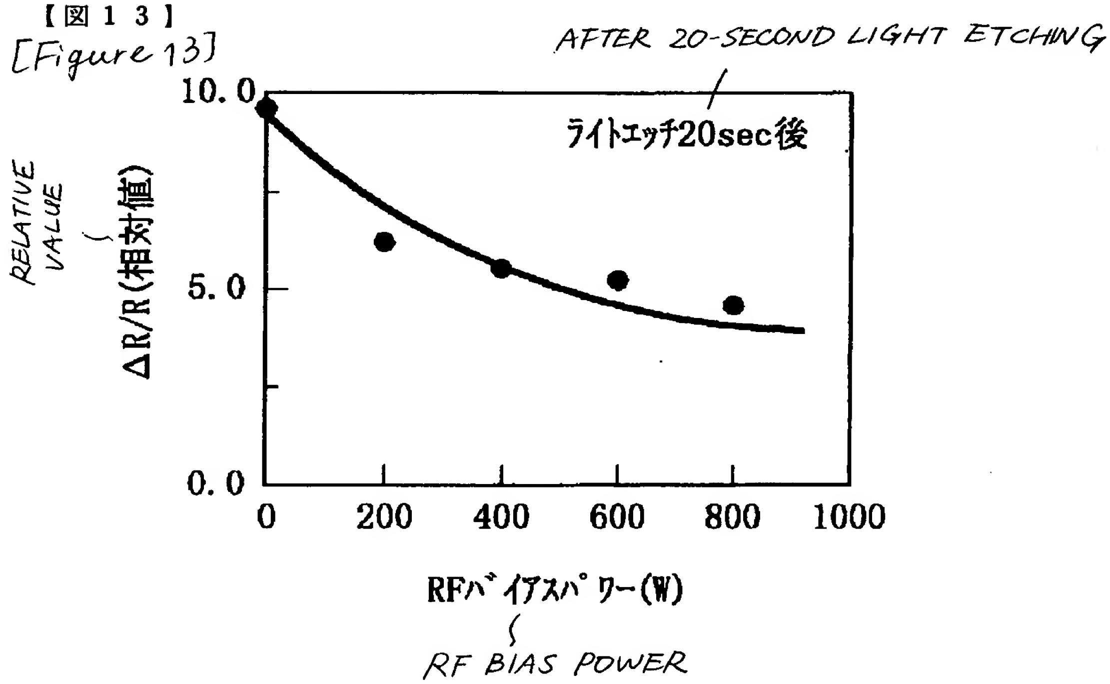
【図１１】
[Figure 11]



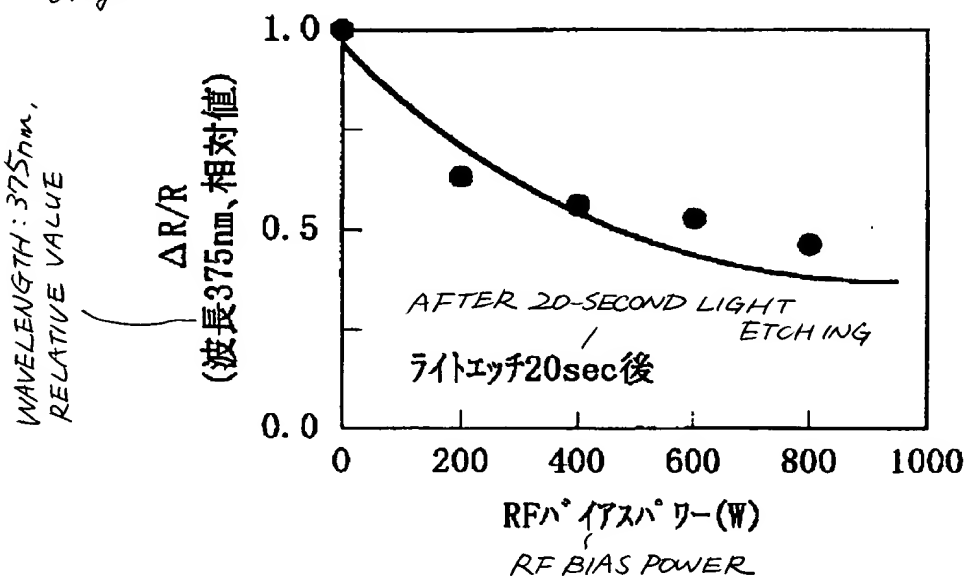
【図１２】
[Figure 12]



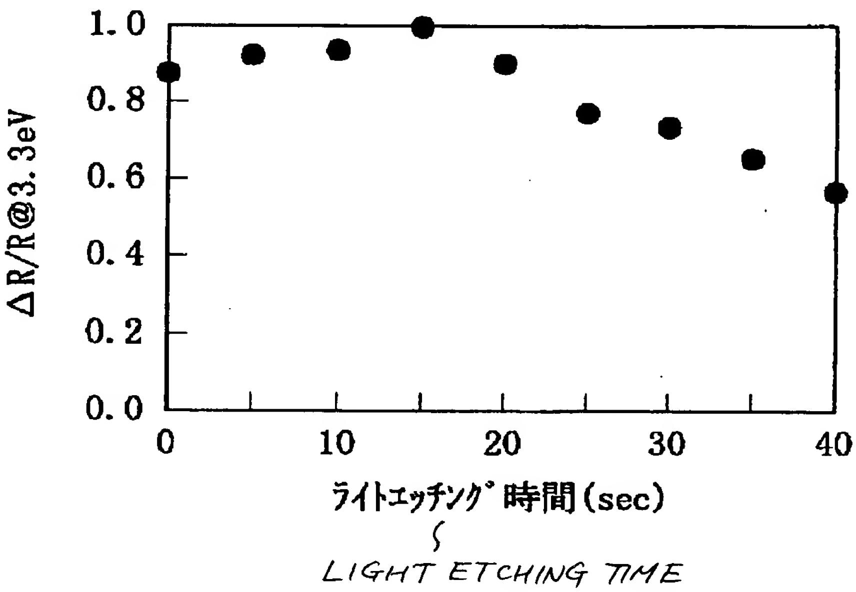
【図１３】
[Figure 13]



【図１４】
[Figure 14]



【図１５】
[Figure 15]



[Name of the Document] ABSTRACT

[Abstract]

[Problem] To provide a method for fabricating a semiconductor device and an apparatus for fabricating the same, which can obtain desired characteristics with high precision and can make them consistent by means of an in-line control.

[Means for Solving the Problem] An n-type source region **108**, an n-type drain region **109** and an n-type semiconductor region **101** are provided on a silicon wafer **103**. An interlevel insulating film **104**, which has been deposited on the silicon wafer **103**, is subjected to dry etching using plasma, thereby forming openings **110a** to **110c** reaching the regions **108**, **109** and **101**, respectively. Thereafter, light etching for removing a damaged layer is performed. During the process, the n-type semiconductor region **101** is intermittently irradiated with exciting light **511** for excitation and the variation in reflectivity of the probe light **507**, which has been incident onto the semiconductor wafer from a direction vertical thereto, depending upon whether or not it has been irradiated with the exciting light **511** is monitored, thereby precisely grasping the degree of progress of the processing treatment by utilizing the fact that the variation rate of the reflectivity differs depending upon the amount of defects in semiconductor.

[Selected Figure] Figure **2**